

# HST imaging of two $z > 4$ radio galaxies

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**Abstract.** We have imaged 8C 1435+635 ( $z = 4.25$ ; Lacy et al. 1994; Spinrad, Dey & Graham 1995) and 6C 0140+326 ( $z = 4.41$ ; Rawlings et al. 1996) in both continuum and Ly $\alpha$  plus continuum bands with the HST. Our images show patchy distributions of continuum and line emission with a tendency for the peaks in the two types of emission to be offset. When compared to Keck  $K$ -band images, it seems likely that the presence of dusty neutral gas is strongly influencing the UV continuum and Ly $\alpha$  emission. The radio and UV emission are not particularly well-correlated, except for a general tendency towards radio-optical alignment. It is suggested that at least some of the observed radio-optical alignment is produced as dust is cleared from the radio lobes by shocks associated by the radio source. If true, this means that 8C1435+635 could be hosting a luminous, galaxy-scale starburst, as suggested by submm observations.

## 1. Observations

### 8C 1435+635

This object was observed in the F814W and F622W filters (F622W includes the Ly $\alpha$  line). Using the Ly $\alpha$  flux of Spinrad et al. 1995 we have produced a “pseudo-Ly $\alpha$ ” image by scaling and subtracting the F814W image from the F622W one. In Fig. 1 we show the F814W image, the “pseudo-Ly $\alpha$ ” image and the MERLIN 5GHz radio map superposed on the Keck  $K$ -band image of van Breugel et al. (1998). (The radio-optical registration should be accurate to  $\approx 1$  arcsec.) The Ly $\alpha$  peaks in the southern radio lobe, slightly offset from a faint patch of continuum emission. The central region has a (resolved) peak of UV emission surrounded by diffuse material. The  $K$ -band image shows that the rest-frame blue continuum is diffuse and covers the whole area enclosed by the radio lobes. The UV emission in the centre of the source is offset to the SW, but that in the southern lobe is closer to the major axis of the  $K$ -band emission. There is a suggestion of a bar of  $K$ -band emission perpendicular to the radio axis across the centre of the source.

### 6C 0140+326

One orbit in each of the F675W and F658N filters was obtained on this object. Both these filters contain the Ly $\alpha$  line, and the emission in the F675W filter was found to consist entirely of line emission. In addition, NICMOS imaging of a nearby high- $z$  field galaxy has also given us a high signal:noise NIC3 image

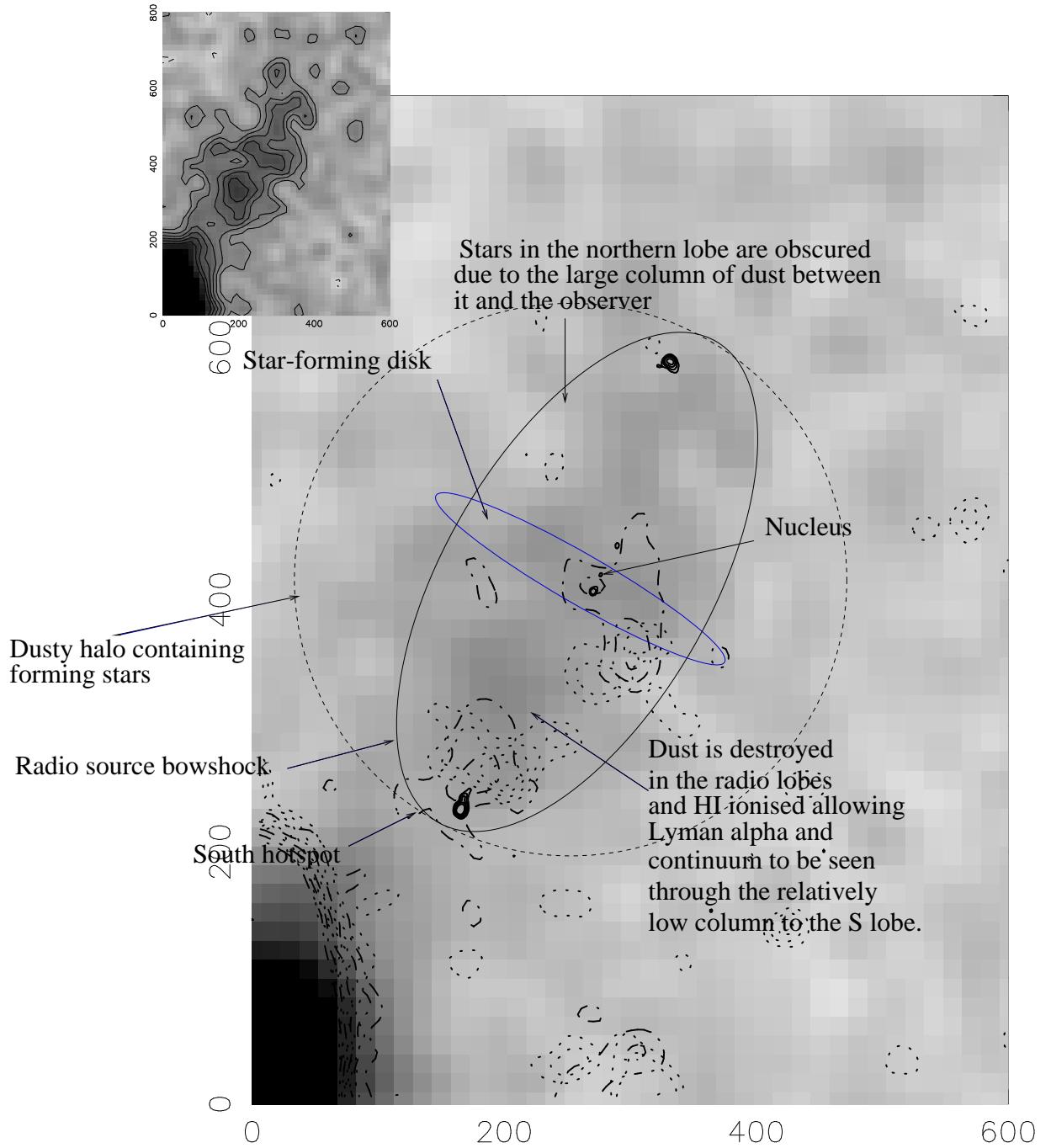


Figure 1. Overlay of the F814W image (dot-dash contours), the MERLIN 5GHz radio map (solid contours) and pseudo-Ly $\alpha$  image (dotted contours) over the smoothed  $K$ -band image of 8C1435+635. Superposed is a cartoon depicting the model discussed in the text (in which the south lobe is the closer to us). The image is  $6 \times 8$ -arcsec in size. *Inset:* the  $K$ -band image of 8C1435+635 smoothed with a  $\sigma = 0.15$ -arcsec gaussian (contours and greyscale). Note the bar running across the middle of the source perpendicular to the radio axis.

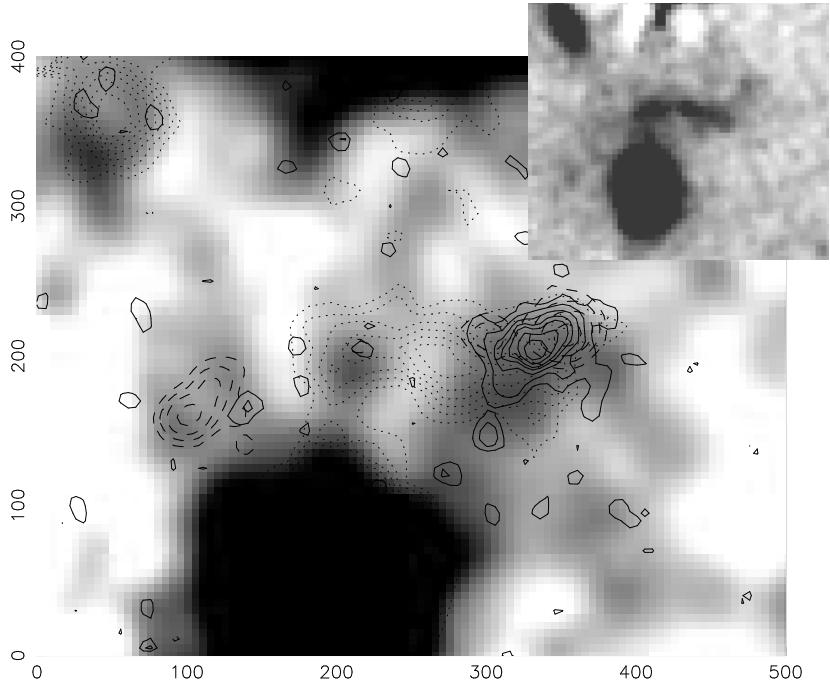


Figure 2. Overlay of the 1.5 GHz MERLIN radio image (dashed contours), Ly $\alpha$  emission (solid contours) and  $K$ -band emission (dotted contours) on a greyscale of an  $I$ -band WHT image of 6C0140+326. Radio-optical registration has been obtained by lining up the putative radio central component with the peak in the UV/ $K$ -band emission. The image is  $5 \times 4$ -arcsec in size. *Inset:* the NIC3 F160W image as a greyscale. In both images the bright star to the north has been subtracted.

of 6C0140. The Ly $\alpha$  image obtained shows that the line emission is only from the western end of the radio source. A UV continuum image from the WHT (Fig. 2) shows marginally-detected UV continuum from most of the area of the radio source, and the  $K$ -band image (van Breugel et al. 1998) is bar-shaped and aligned along the radio axis. The object is being weakly lensed by a nearby galaxy, and this is probably responsible for most of the elongation in the  $K$ -band, as well as the sinuous structure seen in the NIC3 image, although there is probably also some intrinsic radio-optical alignment.

### A galaxy-scale starburst in 8C 1435+635?

The submm detection of 8C 1435+635 (Ivison et al. 1998) implies the presence of  $\sim 2 \times 10^8 M_\odot$  of dust. Although this may be concentrated in the nucleus, as is the case for local ULIGS it may alternatively be distributed on the scale of the host galaxy ( $\sim 40$  kpc), and be heated by a galaxy-wide starburst. If true, this could mean that we are seeing a giant elliptical galaxy forming according to a monolithic collapse scenario.

Dust distributed throughout the galaxy would account for the relatively red UV-optical colour and the patchy nature of the UV continuum emission. Distributed dust with HI would also explain the peculiar distribution of the Ly $\alpha$  emission (Fig. 1) and the complicated velocity structure of the Ly $\alpha$  line (Lacy et al. 1994).

The UV flux and colour of 8C1435+635 is consistent with a starburst: the UV continuum flux corresponds to a star formation rate of  $\approx 170 M_{\odot} \text{yr}^{-1}$  before correction for reddening, if all the UV is from a starburst. The  $F814W - K$  colour corresponds to a spectral index in  $f_{\lambda}$  of  $\beta \approx -1.1$ . Using the models of Meurer, Heckman & Calzetti (1999), this corresponds to an extinction at 160nm of 2.2 mag and an infrared:ultraviolet luminosity ratio of  $\approx 10$ . This is consistent with the far-infrared luminosity of this object as detected by SCUBA ( $4.4 \times 10^{12} L_{\odot}$ ), and implies a corrected star formation rate of  $\sim 1200 M_{\odot} \text{ yr}^{-1}$ . A good test of the distributed starburst theory would be to map the neutral gas directly using CO emission from the galaxy. This should be within the capability of the proposed large mm-array.

Of course, we must remember though that we are looking at a radio galaxy, and the radio source is likely to be influencing what we are seeing. The aligned continuum in 8C1435+635 could represent, for example, the result of dust scattering of a hidden quasar nucleus or inverse Compton emission from low energy electrons in the radio lobes (Spinrad et al. 1995). Nevertheless, the  $K$ -band emission bar across the centre of the source would seem to lie outside any plausible scattering cone, and is therefore probably starlight.

Jet-induced star formation may also be contributing to the aligned light, and the colour gradient in the SE lobe could reflect an age gradient in the stellar population formed behind the expanding bowshock. A colour gradient in the aligned emission could also arise if the radio source is embedded in a dusty halo of young stars, however. Shocks associated with the expanding radio source may destroy dust grains within the radio lobes, resulting in bluer emission from the end of the approaching lobe, as the column density of dust on the line of sight will be the lowest here. This model (Fig. 1) also provides a nice explanation for the lack of UV emission from the northern lobe.

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## References

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